Report 1906

PROTOTYPE MICROFILM PROJECTOR FOR NAVIGATIONAL CHARTS

by

Philip Morrill

August 1967

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
FORT BELVOIR, VIRGINIA

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Task 1M443012D25611

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Military Technology Department

SUMMARY

This report describes the prototype model of the microfilm projector for navigational charts and its supporting systems. This is the first successful, operable shipboard model.

This projector was designed for shipboard installation to replace the chartroom and chart table, at considerable savings. Microfilmed charts save space and offer faster retrieval and filing, compared to paper charts.

Further savings will be realized, after a large demand helps make the full system operable, by a reduction of one man from the crew.

Future models of the system will superimpose radar images over chart images to dispense with many computations normal to navigation.

The prototype model is available for inspection by interested groups, and a 4½-minute motion picture film on the projector is available for showing.

FOREWORD

The authority for this report is Task 1M443012D25611.

The investigation was performed by Philip Morrill, Electrical Engineer, Marine and Bridge Laboratory.

CONTENTS

PROTOTYPE MICROFILM PROJECTOR

FOR NAVIGATIONAL CHARTS

I. INTRODUCTION

1. Subject. This report analyzes the need for microfilming navigational charts and describes the appropriate projector to translate slides into full-size chart images.

2. Background. At the present time, an aircraft carrier going to sea on a worldwide mission must carry 17 tons of paper charts.

Most vessels are designed with a separate chartroom to protect the navigating crew's night vision from the high-intensity light level required on the chart table to read the fine lines currently used on charts. When a projector is installed directly on the bridge, the cost of this room will be eliminated and the navigating officer will be able to stay on the bridge.

This report describes the prototype chart projector developed by the Marine and Bridge Laboratory and outlines future developments necessary in the field.

II. INVESTIGATION

3. The Navigation Problem. The U. S. Army owns and operates a fleet of small ships and large boats. This is recognized and encouraged by the U. S. Navy as a requirement for moving material and personnel from ship to shore. This fleet must be operable in any part of the world.

As long as ships cruise the ocean, some form of chart or map will be required. Some highly sophisticated systems have been developed--mostly offsprings from aircraft navigation techniques--which can produce charts and navigation data on shipboard. One example is an automatic plotting device by which a chart is transmitted by radio, translated on a computer, and reproduced on automatic plotting machines. Such equipment is expensive, bulky, of lower reliability than more elementary devices, and requires maintenance of high-echelon caliber. A ship must have a map service of almost 100-percent reliability for extended sea trips. It is not likely that these complex electronic systems will have any application aboard ships on U. S. Army missions.

Present-day navigation requires plotting of the ship's course on a chart. This requires a chart table of sufficient size to spread out the chart (often 4 feet by 6 feet, top surface dimensions); large storage drawers for storing the charts, if extended trips are made; lighting adequate to read the fine lines of the present printed charts; and plotting tools such as parallel rules, scales, triangles, and dividers.

Location fix of a ship on a chart is secured from the following:

a. Sextant shots.

b. Loran locations.

c. Direction finders.

d. Log readings.

e. Pelorus bearings.

f. Radar.

g. Gyrocompass bearings.

h. Echo depth sounder.

i. Magnetic compass.

j. Radio.

Customarily, all of these data sources are available and plotting requires several of them. As these data never agree exactly, the assumed position may result from an average of several location calculations, as weighed by the navigating officer in the light of his experience and/or biases.

Sextant shots require clear weather. A Navy triangulation crew once spent 5 weeks on the Red Sea and obtained only 3 sextant readings.

Loran depends on complex electronic equipment which picks up signals from master and slave stations ashore. These stations are limited mostly to CONUS coasts and are divided into two systems--A and C. Many ships carry equipment which operates only on Loran A system; the Loran system does not exist for them when they navigate in waters with Loran C coverage. Most of the world has no Loran coverage, but a few areas have a Decca navigating system available. This system allows a ship to locate itself with high accuracy but requires shore stations only a few miles apart. When Loran is used at longer ranges, the errors become too large for practical safety. No additional Loran shore installations are expected to be built.

A direction finder is basically a radio with a directional loop antenna. Pointing this antenna to the center of the null or no-signal areas gives a bearing of the received station. Bearings are rather broad, but the system has the advantages of simplicity and reliability of equipment.

Dead reckoning was the old standby. The log reads water speed. By referring this to a previous fix and to the known passage of time, the relative position of the ship is plotted. Time and speed values give the distance traveled. Direction is determined by compass, radio direction finder, or pelorus reading. This is in error by the amount and direction of currents and ship's leeway.

Pelorus shots are bearings taken by line of sight on lighthouses, headlands, etc. They are limited by the availability of known objects (shown on the charts) and daylight with suitable weather to allow visibility.

Radar shows objects within its range (possibly 40 miles) and can be used at night. Bad weather can limit its range, but it will have weather penetration exceeding that of the human eye.

Courses today are usually set by gyrocompasses. This not only yields exact bearings, but it allows the use of repeaters which give compass readings in various parts of the ship, and which provide connections to radar, direction finder, and pelorus. The gyro, as with all complex devices, leaves much to be desired in reliability; a magnetic compass is used as a check and as a backup.

Magnetic compasses are subject to stray magnetic fields which exist in every ship and which must be frequently compensated for, and readings must be converted from the existing magnetic North Pole to true north.

Normal navigation consists of approximating the ship's position on a chart by several devices and selecting an assumed position from one or an average of these. The ship's bearing is noted on the chart rose (a primed compass circle on each chart oriented to true and to magnetic north, in respect to the chart), and transferred across the chart by parallel ruler to the previous ship's position. The ship's course is drawn as a line from the previous position and extrapolated to locations ahead.

The helmsman steers directly by compass on the courses given to him by the navigating officer. He is not allowed to change his assigned course, even if he sees the Rock of Gibralter looming directly in front of him. A ship is also handicapped in that a mile or several miles may be required to stop the ship, and the turning radius of a ship is large.

Thus, it is seen that navigation, at its best, is a rather inaccurate procedure. In 1965, the 800 ship groundings were proof of the fallibility of the existing navigation system. The recent tanker disaster off the English coast provides even fresher proof.

Electronic gear is expensive and often breaks down during a voyage; as it ages, its reliability decreases further. Ships cannot economically nor continually upgrade this high-priced equipment, yet it is fallible to the shock, vibration, and marine atmosphere of sea transport.

It is of as great or greater concern to locate other ships in the area and to know their bearings and courses. This is done by direct observation, radar, and radio. The chances of equipment failure or human error are further increased, depending on the number of ships in an area.

In good weather, navigation, in the sense of avoiding groundings and collisions, is dependent mainly on human vision. At night, vision is limited; the impact of light on human eyes, even light of rather low intensities, results in temporary blindness at low light levels. Twenty minutes are usually required for restoration of normal vision. Red affects the vision less than the shorter light wavelengths at the blue end of the color spectrum. Radar phosphors in England have been made in red and red-orange instead of the blue and blue-green used here. A red light appears dimmer to the eye than a yellow light, but, to preserve night vision, red lights on dials are further dimmed by voltage control. Chart tables are often used with low-level red lights at night.

4. The Chartroom. A chart requires 35 foot-candles of light to be seen well. Much more could be accomplished with present-day charts if they were printed with heavier lines, more saturated colors, and larger type. Until this is done, we must use the currently available charts. Seamen are often farsighted and, thus, handicapped in close work.

The relatively high-level chartroom light must be isolated from the bridge at night, and, for this purpose, space and money are allocated on most ships for a separate chartroom. On a few ships, the chart table is placed on the bridge and curtained off from the rest of the bridge. Passage of people through the curtains results in flashes of light.

When the chart table is enclosed in a separate room, the navigating officer must leave the bridge and disrupt communications with the helmsman, who continues to steer blindly, increasing the possibility of casualty.

5. Notices to Mariners. Charts age rapidly. A ship may sink and become a menace to navigation, or there may be a buoy change, or new bridge construction. The mariner must be informed of all these hazards, which are more recent than his charts, but charts can be revised and reissued only after periods of several years, when there are sufficient changes and sufficient demand to make the reissue economical.

Temporary changes and changes not shown on the chart are issued in a printed bulletin. This verbal description must be transferred by hand, aboard each ship, onto each chart as graphic symbols. A destroyer requires the full-time services of one man to accomplish this job. Obviously a larger, farther-ranging ship requires more manpower.

A meeting at the U. S. Navy Oceanographic Office established the procedure for production and use of these notices. A change received at the Oceanographic Office is marked on the appropriate chart. When the number of entries on a chart warrants, the changes are written out and submitted to the Government Printing Office (GPO). The GPO sets these on printing presses and runs off proofs. These proofs are returned to the Oceanographic Office where they are checked for accuracy and returned to the GPO. The GPO enters the changes and prints and mails the official "Notices to Mariners." The whole process requires many weeks.

The prototype projector and the microfilm system described in this report make it possible for the Oceanographic Office to immediately photograph, in monochrome, each change as soon as it is received. The resulting transparencies would be sent by automatic computer system to each registered holder of the chart within a few hours. The chart holder would drop this overlay into the slide holder of the projector, over the chart microfilm, where it is automatically lined up with the chart by pins. Thus, errors are reduced and, obviously, a relatively few man-hours of work at the Oceanographic Office can replace hundreds of man-hours of work aboard the ships.

Every private shipping operator, every ship's master, and every Government agency operating ships will save money.

III. DISCUSSION

6. The Microfilm Approach. The logical solution to some of the problems previously described is through microfilmed charts. Their physical bulk will be a fraction of that of the paper charts. The problems of storage and filing are much simpler than for the full-size chart. Retrieval of microfilms is possible with several methods, all of which are superior to the handling of paper charts. Handling of paper charts on smaller craft, especially in a wind, is difficult.

The advantages of chart accessibility on the bridge are well known but they are offset by the scatter of the high light required. A rear-projection device, however, can enclose the light and there would be no overhead or outside lighting to stray into other areas (Fig. 1).

An image caught on a screen by rear projection can operate with a sharp angular cutoff. A ceiling with a black paint coating above the screen will absorb upward scatter without reflection.

Due to the unavoidable period of transition from paper to microfilm charts, the screen will have to be of a size sufficient to permit its use as a chart table (Fig. 2).

7. The Chart Projector. The design of the fleet of Beach Discharge Lighters, Mk. II, is well along. Elimination of the chartrooms on these craft can more than pay for microfilm projector development.

A decision was made to produce a prototype microfilm slide projector. The screen size was for projection of a maximum 36- by 42-inch image, based on a scale of 1:1 with the original chart. About 2 percent of all charts are larger than this; but these can be split and parts placed on two slides. The maximum press size is 60 inches, and charts are printed in many sizes up to this dimension and to many scales without rule or classification.

The projector design must meet maritime conditions. These include: pitch and roll, to Navy specifications; a 30-degree roll to either side; a 10-degree pitch; a permanent list of 15 degrees to either side; or

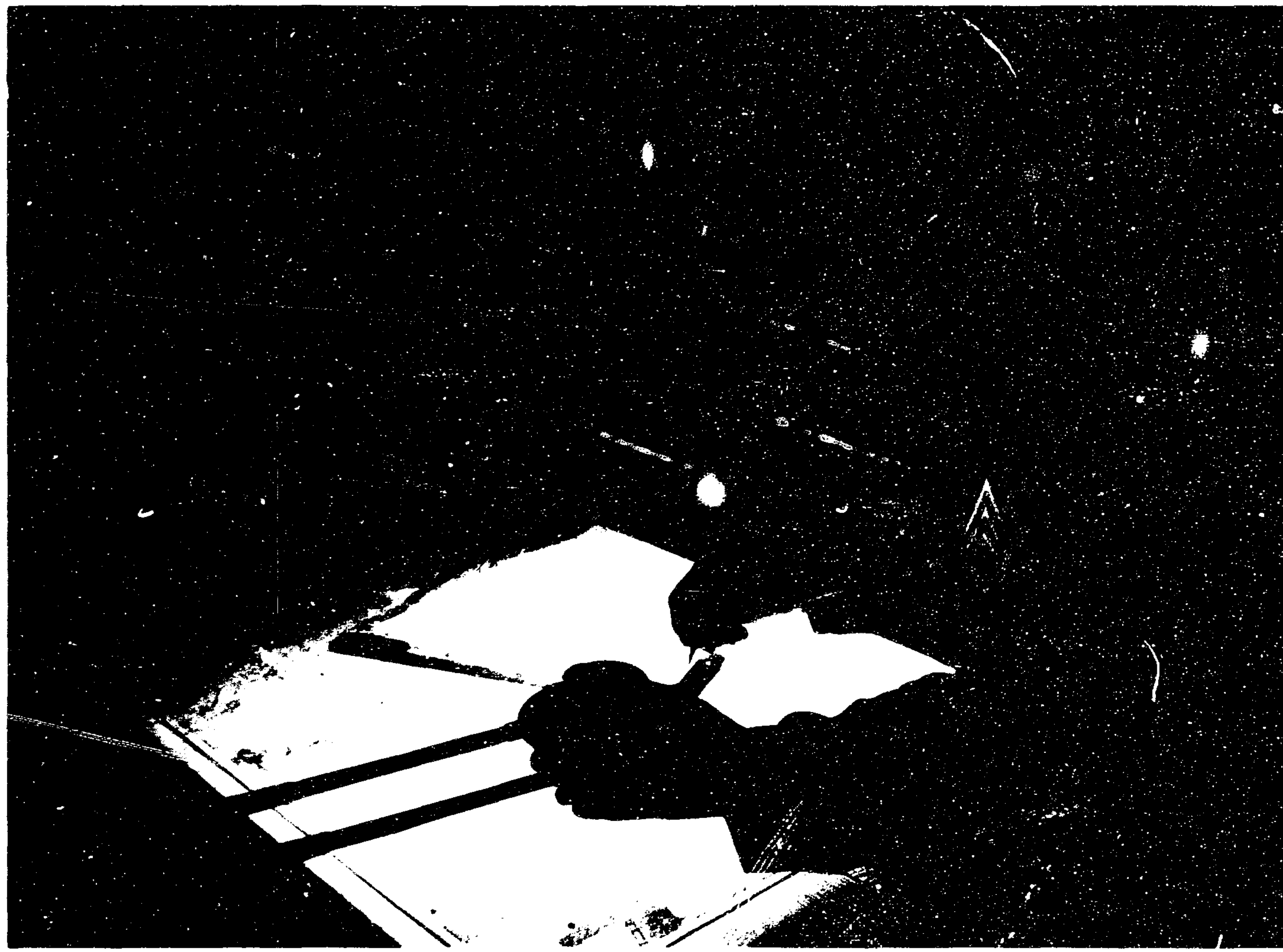
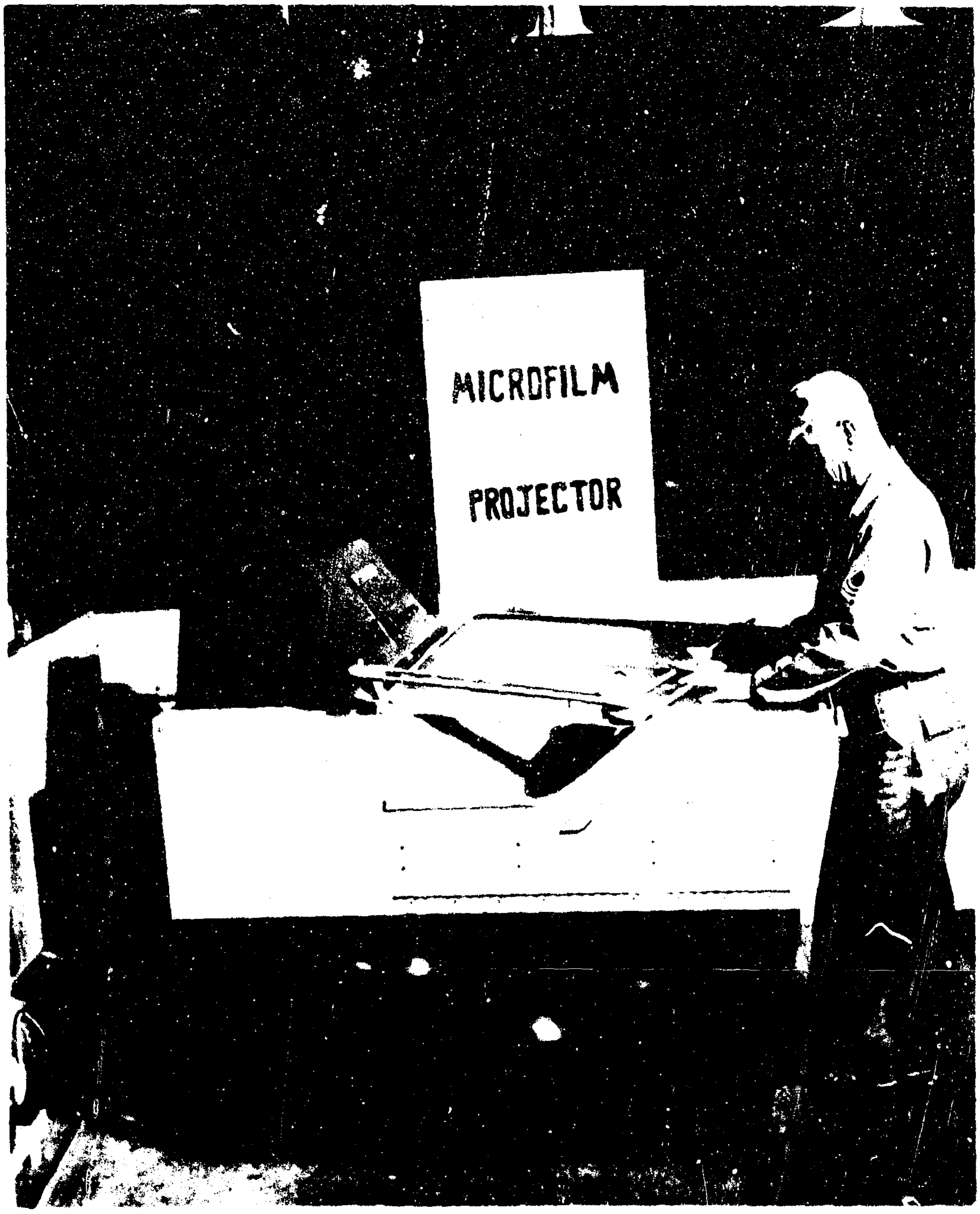


Fig. 1. Plotting course on projected image of a chart. N11056



N10320

Fig. 2. Prototype projector for navigation charts.

a 5-degree permanent trim fore and aft from which displacement must not exceed 1/16 inch.

Projector installation will usually be several decks above sea level, but the design must allow for humidity and salt atmosphere. Accelerometer installations made on the U. S. Army Vessel "Hickory Knoll" always remained below 1G readings. The projector shock was analyzed by Barry (a shock mount manufacturer) and shock mounts were specified.

The navigating officer may lean on the screen to plot his course, and, in some cases, people may accidentally fall against the screen. Specifications require that a 100-pound sandbag on any point of the screen not deflect the projected image more than 1/16 inch.

The screen material must control light, and a polar-coat screen can cut off light so that, at 30 degrees off the edge, light is reduced to 8 percent of the normal. A 3/8-inch screen meets the strength and rigidity requirements.

The surface of the screen must allow course plotting. A polarcoat will take the mark from a fine water-soluble wick pen such as "Pentil" or Esterbrook "Clearwriter." A mylar overlay can be used, if desired, to increase the life of the polarcoat. Either material can be erased with ordinary rubber erasers.

A sheet of vellum may be pulled off a roll and the course traced and filed for reference. The Oceanographic Office has received legal opinions that these sheets would be accepted by admiralty courts as legal evidence in hearings on casualties. A camera used in the radar system could be mounted so as to swing over the plotting table and record the course on film.

Plotting is accomplished by a modern drafting-machine arm instead of with small, separate pieces of equipment.

The desired slope of the screen, toward the front, was the subject of considerable discussion among USAERDL, "T" School, and Itek Corp. Proposals ran from 15 degrees to a flattop; 5 degrees were agreed on.

Control of light by voltage, from very dim to full, was accomplished by a solid-state voltage control. The lowered voltage lowered the Kelvin temperature, and it was feared that this red shift would cause misinterpretation of some of the subtle pastels on chart A neutral density filter of 1:10 passing value was installed for insertion in the light path, as required. A similar red filter for night use was installed. The value of the red filter was chosen after tests at sea on the "Hickory Knoll."

A 1000-watt tungsten projector lamp rated for 25 hours of life would require replacement once a day, if the projector was in steady operation. A built-in standby system allows lamp operation at a low voltage between periods of use. Otherwise, the thermal shock of turning the lamp off and on would result in a life as short as that permitted by steady burning. A heater in the lamp chamber prevents condensation, which could break a cold lamp. A lamp usually solders itself into its socket so that an attempt at removal breaks or pulls the glass envelope loose. A push rod must be used to apply lifting pressure to the socket to push the base loose.

One thermostat prevents the lamp from burning, in the event that the blower does not operate or the lamp runs over normal temperature, while another thermostat keeps the blower running, after the lamp is turned off, until the lamp drops to normal temperature.

The types of available projection lenses are numerous. A short-focus (wide-angle) lens, proposed by one contract bidder, would result in a bad fall-off of image sharpness between the center and the edge of the screen, due to high curvature of the short projection radius. A longer, focal-length lens requires a longer distance from lens to screen. This lens can be reduced in bulk by folding with mirrors. The image goes to a mirror and is reflected back over its original path, halving the required package space. The image may be folded several times with further reduction in room; however, more than one mirror requires complex adjustment and increases cleaning needs. A decision was made to limit to one mirror the precision folding design and to use an off-the-shelf, Schneider, 180-mm, Componon enlarging lens. Another bid would have required a subcontract to Leica for a more expensive handmade lens.

8. The Prototype Projector. The prototype projector was constructed by Itek Corp., Lexington, Mass., who was selected from among three bidders on USAERDL specification. The projector was delivered to USAERDL on 11 November 1966, after a three-day exhibition at the Sheraton-Park Hotel, Washington, D. C.

The cooling system delivers 125 cfm of air. The lamp light passes through heat-absorbing and ultraviolet-absorbing filters, before it reaches the slide, to protect the transparency colors. A condensing lens is next in the system, then a small mirror changes the light path 90 degrees, from horizontal to vertical, to pass through the horizontal slide. The slide is next in path, then the lens, and, finally, the main mirror of aluminum-oxide-coated, half-inch glass. The image, reflected on the underside of the screen, is enclarged 9 times the size of the chip and is on a 1:1 ratio with the original chart. The mirror is adjustable on a three-point, safety-head, capscrew mount. No external focusing is used to avoid local misreading of the image and change of image scale. There is no parallax problem.

The entire projector system is packaged in black, crackle-finished, marine aluminum and has a total weight of 600 pounds. It is designed for welding to deck plate and can be separated at the center into two halves which can be passed through a 30-inch doorway.

It requires a 115-volt, 60-cycle, single-phase, 1400-watt power input. Due to the solid-state dimmer, direct current cannot be used.

Slides are inserted in tandem, and either of the two may be turned 90 degrees. The holder is designed for glass-bound slides. Interface from one chart to the next is allowed by Y-Y control of the slide holder.

9. Slides and Microfilm. A projector is no better than the quality and availability of slides. A probable reason for the delay in commercial availability of a navigation microfilm projector, an obviously desirable piece of equipment, has been the lack of suitable slides, a guaranteed supply of these slides, the lack of compatibility between projector and slides, and slide prices.

Slides of very high resolution are required. Early development efforts proved that color film on 70-mm stock could not meet the resolution requirements and that 105-mm slides were the minimum.

Manufacturers of color film seem optimistic about their products and claim resolutions of up to 200 lines per millimeter. USAERDL requires about 60 lines per millimeter, probably a reasonable achievement, but contractors who promised 60 lines per millimeter delivered only 20 lines. New efforts raised this to nearly a 40-line resolution. Special laboratories offered 6 chips at 60 lines per millimeter for $4800, and the standard photofinisher offered the poorer chips at $25 each, plus $30 each for glass mounting. The image-floated-onto-glass, recommended by Eastman Kodak, was unknown to the laboratories, and we did not ask for a quote on it.

The Oceanographic Office, which makes the navigation charts and writes the "Notices to Mariners," appreciated the potential of this system and was willing to try microfilming to the required specifications, with the view that an immense demand for such chart microfilms must inevitably come.

The Oceanographic Office has a special high-precision camera, in a seismographic-isolated, machined, cast-iron frame, with a Goerz hand-assembled lens. The first charts photographed with this camera produced slides appreciably short of the definition needed.

They discovered that light, reflected from the walls of the room, was bouncing around in the lens and causing a loss of several lines per millimeter of definition. The room was painted black. The lens, set in a precision mount, was measured and discovered to be a minute amount out of line. This was corrected by insertion of a takeup screw. An Ansco engineer determined that more green was required in the light. Green plastic sheets were installed and cut back until the proper amount of color correction was introduced. Three days were spent in minute balancing of exposure against development. A specially constructed, isolated shutter was installed so that the vibration of the shutter would not offset the precision. The slides exceeded 56 lines per millimeter resolution, and recent advances in technique have increased this to more than 60 lines per millimeter with fine color and contrast. Itek Corp. subjected slides, made by several sources, to optical analysis and was quite critical. Itek then tested Oceanographic Office slides and reported that they had not believed such fine slides could be made.

These quality controlled slides may be produced for 75 cents each for labor and material, when a volume demand occurs. A paper chart retails for $1.00 to $1.25 each, and the advantages of the microfilm might justify a unit price of $1.50 to $2.50. Volume production of slides can be warranted only after a considerable number of projectors are produced and in operation.

The original slides were bound in glass. Various thicknesses were used. Glass of 1/16 inch was very fragile, and two pieces of the 1/8-inch glass, plus film, added up to more than a 1/4-inch total thickness, which was unwieldy. Change in glass thickness changes focus. Plastic will be tried in thin pieces. The new slide holder, soon to be funded, will have two pins, while the film and covers will have matching holes. The assembly will automatically line up as soon as it is dropped over the pins.

All charts are standardized by the ANCIF system, whether made by the Hydrographic Office, Coast and Geodetic Survey, Admiralty, Canadians, French, or others. An ANCIF digit will be assigned to these slides for international identification while the format is now listed in the standardization of Army microfilms. Microfilms of charts will carry a 14-mm tab bearing the following:

a. Chart name.

b. ANCIF chart identification code number.

c. Address of the slide manufacturer.

The remaining portion of this tab will carry retrieval holes.

Retrieval will be by needle. An index will designate the route to be cruised and the retrieval letter or letters. Should a Norfolk-New York course be anticipated, the index card might designate this as "B." Insertion of the needle in hole "B" through all the films in the file will allow lifting out of only those applicable to this route. Even should the "B" trip films be filed out of order, retrieval will extract the proper films.

10. The Prototype Installation. The projector was shipped to Fort Eustis, Va., and was installed on the U. S. Army MV "Sagitta" on 5 January 1967. The "Sagitta," a former net tender, was remodeled and is used as a training ship at sea for classes in celestial navigation. The ship is 260 feet long and is rated at 2600 tons. The direct-drive propeller normally operates at 250 rpm.

The projector was disassembled into two halves, and moved to its assigned stateroom on 03 level where it was fastened to the deck plate with welded angles.

a. Projector Sea Trials. The projector was taken to sea on two short trips of a few days each.

On 6 March 1967, the projector was taken on a 2-week sea trip to San Salvador. The ship was subject to several days of severe winds, 30-foot seas, and a day or more of 60-mph winds. On its return, the ship was placed in a shipyard for repair and was returned to Fort Eustis on 20 April 1967.

The projector underwent sea tests as severe as it is likely to encounter. There was no measureable image shift. The projection lamp, rated at 25 hours of life, burned for 114 hours at full voltage. Many small bolts loosened, the filter glasses broke, and a number of small details showed need for correction in the next model. On the same trip, the gyrocompass was out, the radar operated intermittently, and the main 500-kc radio was out of operation.

Reliability is expressed in mean time between failures (MTBF). This is not applicable for shipboard use. A ship must have nearly foolproof equipment when at sea. Failures must be correctable on board ship with limited skills, tools, and parts. Highly sophisticated equipment may not be repairable even in port, if the specialized skill required is not available. Preventive maintenance in port often introduces as many faults as it removes. Other failures may require so much time to locate and repair that normal length of stay in port is not sufficient, and the ship must either lose mission time or go to sea with inoperable equipment.

b. Slide Holders. A contract extension is now placed for redesign of the slide holders. The new holders will allow rotating each film chip 360 degrees. This allows orientation of the chart image with the ship's course. The slide holder will be movable by rack and pinion for image shift on the X-X axis and by slide on the Y-Y axis. Positioning will allow any quarter of the image to be presented on any quarter of the screen. Future models will have slide controls remoted and operable from the front control panel.

The new slide holder will carry two pins for stacking and alignment of two or more transparencies.

Fabrication and installation of this holder should be completed by 15 June 1967.

11. Impact of the Projector. Inquiries have been received from many Government agencies in regard to this projector. Firms such as Humble Oil, Shell Oil (Par[illegible]), Eastman Kodak (England), an English marine journal, Canada, and the city of Minneapolis have requested price quotes and specifications for this unit.

The projector system appears not only to fill a real need for Army (and Navy) vessels, but its reduction in operating costs has appealed to commercial operators also. A potential wealth-producing industry may be added to the economy.

The value of the projector system is dependent on demand for slides. The greater the slide demand, the greater the flexibility and the more numerous the improvements that can be made. It is, therefore, desirable that as many projectors as possible be used on non-Army vessels. Only when slides are available in volume can the utility of slides be maximized in areas such as "Notices to Mariners," retrieval, and identification.

12. Future Projector Development.

a. Radar Image System. It is simple to incorporate the radar image and superimpose it onto the chart image. The radar image is of the polar type, with the ship located in the center.

When the radar image is aligned with the chart image, the position of the ship is accurately located without computation. Locating the radar image two or more times, with an intervening time lapse, not only gives the real course of the vessel, but gives the courses of other vessels in the area so that these may be projected and collision courses determined.

This device should significantly reduce the dangers of collisions and groundings.

The new model will not only incorporate this device, but will remedy the faults found in sea trials of the prototype. Furthermore, the new model can be appreciably reduced in size and yet retain the full 36 by 42-inch screen and chart table capabilities. The acuity and intensity of the image will be increased.

b. Miniaturization. Still another model (Fig. 3), on a quarter-scale, is needed. This model would be so small that it could be carried like a small clothes locker. The operator could choose, at will, a quarter-scale image of the full chart or a full-scale image of any quarter of the chart. This model would then be available to LCMs, as well as Navy PT boats. It has already been requested for aircraft use. This model would be quickly adaptable to a 35-mm, continuous strip map, in place of the 105-mm chips, and would be a logical installation for use in inland waterways.

Previous design and experience can be applied to development of a production model. Many features in the prototype can be picked up as nearly final in design, at appreciable cost savings.

c. Added Features. There are many sophisticated possibilities for additions to the basic projector. Some of these are as follows:

(1) Automatic dead reckoning.

N8418

Fig. 3. Mockup of a future miniaturized projector.

(2) Automatic position mark from Loran, or its equivalent.

(3) Inputs from gyrocompass and/or radio direction finder.

(4) Automatic chart plotting or information addition from radio.

(5) Automatic slide retrieval by computer.

(6) Worldwide film bank in cassets with computer selection.

It is possible that these devices could be designed as add-ons to one standard basic projector.

The projector, in its present form, has the assets of simplicity and high reliability; not much can get out of order. The MTBF will be high, and repairs (chiefly lamp replacement) can be made on board ship.

The more sophisticated devices have a high failure rate, especially under the shock, vibration, and atmosphere at sea. High-echelon maintenance is not available, on the types of small ships the U. S. Army operates, and is relatively scarce ashore.

The development of sophisticated devices requires huge funding, and the final equipment is costly. The basic production projector should be simple and low in price.

d <u>Reduction in Slide Size.</u> This system now operates at the extreme limits of resolution. A small reduction in resolution results in partial illegibility on the projected image. This results in a requirement for excessive quality control in slide manufacture, which must soon enter mass production techniques; and a requirement for excessive maintenance of the projector, which must withstand all kinds of abuse in a variety of marine installations.

Slide-image resolution is determined by the following:

(1) Photogenic qualities of the original chart.

(a) Sizes of lines and faces of type.

(b) Saturation and contrast of color.

(c) Quality of printing and paper.

(2) Resolution of the projector optical system.

(a) Lens resolution.

(b) Screen resolution.

(c) Mirror losses.

(d) Cleanliness and lineup.

(3) Resolution of slide.

(a) Capability of the film.

(b) Optical system used for photographing.

(c) Quality control in processing.

(4) Limits of resolution of the human eye, 8 to 10 lines per millimeter delivered.

It is hoped that the delivered resolution can be increased by 50 percent. This would allow the use of 70-mm film in place of the 105-mm film. The resulting reduction in size would enhance projector size, allow slides to conform to the Defense Intelligence Agency 70-mm standards, allow continuous strips to be used, and assist in the production of slides.

The design of chart printing was controlled in color by the requirement for contrast under red viewing light. Aesthetically, these charts are beautiful drafting and printing products. Practically, a great improvement in legibility and photogenics can be made by using more saturated colors, bolder faces or larger type, and by increasing the weight of lines. However, it may be a long time before these inevitable improvements are realized. The large variety of charts means that a long period is required for redesign of all charts. In the interim, the projector must be capable of projecting the least legible chart and cannot be changed until every chart meets the new standards.

Considerable analysis of economic factors and scientific design of the projector has been made. A 60-lines-per-millimeter resolution slide at 9 times image magnification would ideally deliver a 5.4-lines-per-millimeter image on the screen. The screen resolution is limited to 8 to 10 lines per millimeter by its inherent characteristics and by the resolution of the human eye. The Componon lens now used delivers 80 lines per millimeter ideally (center), and costs $150. A Wild (Swiss-manufactured) lens costs $5000 and delivers 100 lines per millimeter. The total gain to the overall system by the better lens is hardly perceptible, except in reduction of edge fall-off. The addition of 50 percent to 100 percent to the production projector price will appreciably reduce the number installed.

The main hope for gaining the added resolution must come in the slide. The slide quality is dependent on the quality of available color film. Kodak is said to have developed a 200-lines-per-millimeter film. It will not be marketed until a sufficient demand is established. Gevaert has a 200-line-per-millimeter "Scientificolor" film available in Europe. It is available here only in bootlegged samples.

There is no question that film will be available and that slide manufacturing techniques will be improved so that 100-lines-per-millimeter resolution will be available, but the date of this availability is uncertain.

The time will come when 70-mm film will deliver a full-scale chart image with full detail. It is probable that 35-mm film can be used on the miniature model (Fig. 3), with only a minor added quality requirement, when the 70-mm film is practicable for the larger projector. Until that time, we must use 105-mm slides.

e. General Applicability. A projector without slides is useless. Slides without a projector are useless. A single projector, or even several projectors, are limited in use, since the demand for slides is not sufficient to allow full capabilities of the system to be exploited. Only after several hundred projectors are in use will the slide support reach a volume allowing the "Notices to Mariners" overlays, low slide price, and high availability of slides. The situation is analogous to the first automobile, which travelled mud and dirt roads and found gasoline was available only with difficulty.

The U. S. Army, at best, can use only a limited number of projectors. Real volume must come through use by the U. S. Navy and private shipping.

The quantity of projectors purchased, especially for civilian use, will be a function of the price. The projector must be kept simple so that it will be low in cost.

It is not practicable for the U. S. Army to get into the projector business, yet all projector installations will benefit the Army by improving the slide supply. The Army can indirectly aid in increasing the number of installations by publicizing the unit. A projector is available for examination, and a short, 16-mm silent film showing the projector in operation is available for showing.

The time element for securing projector modifications and a guaranteed slide supply is vital to the success or failure of the system. If inquiries cannot be answered within a reasonable length of time, potential users may be lost and the whole project may earn a bad reputation.

IV. CONCLUSIONS

13. Conclusions. Development experience on the prototype slide projector system, which was designed for installation aboard small ships to replace both chartroom and chart table, has led to the following conclusions:

a. The chartroom can be eliminated from ships.

b. The navigating officer can remain on the bridge.

c. Microfilmed chatrs will save space and offer faster retrieval and filing, compared to paper charts.

d. Further savings will be realized, after a large demand helps make the full system operable, by a reduction in crew complement of one--the man who is required to handle "Notices to Mariners" and chart ranges.

e. It will be possible on future models of the system to project radar images over chart images to dispense with many computations normal to navigation.

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13. ABSTRACT

Description of a microfilm projector for navigational charts for shipboard installation. The prototype model tests and corrections, as well as the direction of future developments, are described.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Navigation						
Ships						
Charts						
Maps						
Microfilm						
Projector, microfilm						

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